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# A SYSTEM FOR COOLING LIQUID OXYGEN TO 58 K

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In developing the power plants for the single-flight spacecraft "Buran," the need arose to cool a large volume of oxygen (for a period of ~40 h) to 58 K. A new procedure for the cooling of liquid oxygen in a heat exchanger with evacuation of a non-freezing coolant was developed in this connection.

Regular operation of the integrated-dispatching-control (IDC) unit calls for the use of liquid oxygen at (65 ± 5) K. Considering the inevitable loss of cold (heat flows to the structures, the procedure of work production, etc.), it is necessary to cool the oxygen reliably to a lower temperature – to (57–58) K with its simultaneous cleaning of $N_2O$ and $CO_2$ impurities, since at the indicated temperatures, these impurities are in the solid state and clog the intratank intakes.

It is possible to cool liquid oxygen by two means – by extracting the heat as it boils with evacuation of the vapors, or by heat transfer in a heat exchanger with evacuation of coolant vapors.

Oxygen was cooled under laboratory conditions to 58 K by evacuating its vapors to a vacuum of 0.1 mm Hg. Vacuum pumps with a high evacuation rate, which are safe for operation with oxygen vapors, were required to cool the oxygen by this method on industrial scale. The development and fabrication of these pumps, however, represented a long-term process.

Using liquid nitrogen as a coolant, it is possible to cool oxygen in a heat exchanger only to 63 K – the freezing point of nitrogen. A system, which includes a cryogenic heat exchanger with a coolant – helium, which can be cooled with liquid hydrogen – has been developed by the RKK Énergiya for the cooling of oxygen. According to safety specifications, however, this system is unacceptable for development of the engines and IDC systems, which was being carried out at the testing grounds of the complex.

The State Institute of the Nitrogen Industry (SINI) and the Ural Car-Building Plant recommended a method of cooling liquid hydrogen to 57 K in a heat exchanger with evacuation of coolant vapors – a mixture of liquid oxygen and nitrogen.

*Basic advantages of the proposed coolant are:*

• the minimum (as a function of composition) freezing point is 50 K;

• cooling to 57 K is achieved by evacuating the vapors to a vacuum of 18 mm Hg; and

• the bulk concentration of oxygen in the evacuated vapors does not exceed 10%.

The last two advantages permit the use of VVN and NVZ types of series-produced air pumps.

Moreover, the components of the coolant are less expensive than liquid hydrogen, and, as calculations indicate, the cost of the volatile coolant is 653 rubles lower than that for volatile liquid hydrogen for the cooling of each ton of oxygen (based on 1984 prices).

A system for cooling liquid oxygen in a heat exchanger using the proposed coolant was fabricated at the Ural Car-Building Plant in 1983 on the basis of a technical assignment given to the RKK Énergiya. *The system (Fig. 1) includes the following:*

• heat-exchanger unit *1*, consisting of an internal vessel for cooled oxygen and an external coolant-filled vessel, which are mounted in an insulating housing on a flat car;

• adsorption filter *2* for cleaning impurities from the oxygen that is charged into the unit;

• feed-maintenance unit *5* for the preparation and temperature control of the coolant prior to charging and recharging of the inner cavity of the unit; it contains an insulated container mounted on a flat car, and a system for the evacuation of coolant vapors, which consists of VVN2-50 pumps *6* with a maximum vacuum of 150 mm Hg and NVZ-500 pump *7* with an effective vacuum range of from 150 to 0.1 mm Hg; and

• a system of cryogenic pipelines for charging the units with liquid oxygen and nitrogen, and pipelines for the evacuation of coolant vapors.

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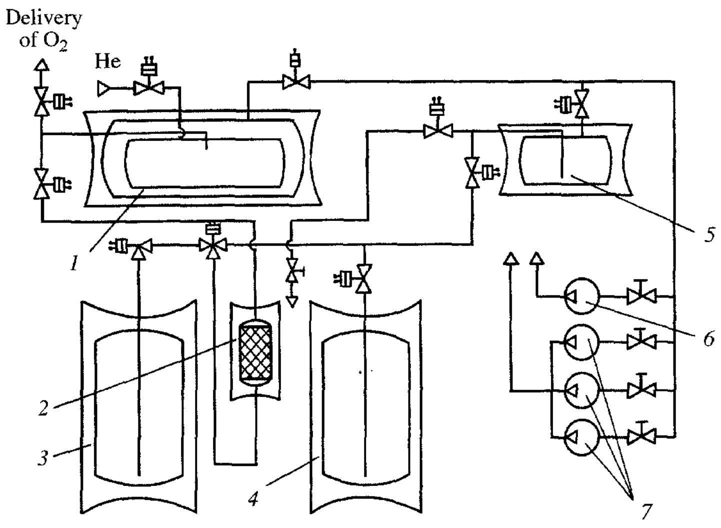


Fig. 1. Schematic diagram for cooling of liquid nitrogen.

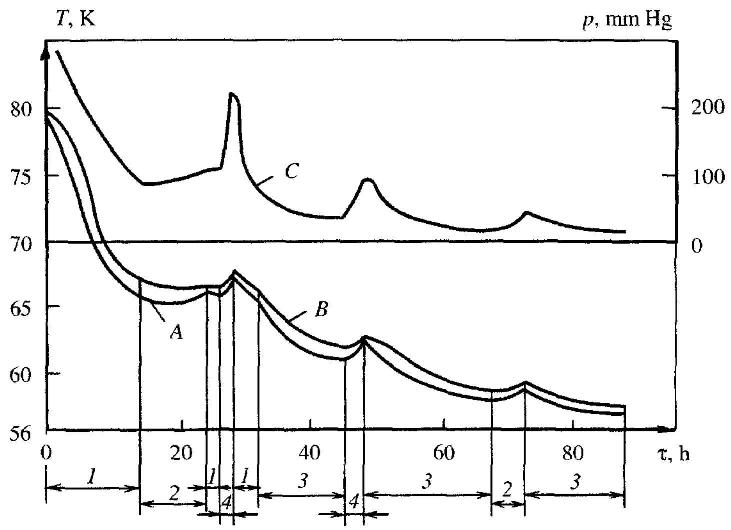


Fig. 2. Standard curves of oxygen temperature $T$ and residual pressure $p$ in coolant cavity versus cooling time $\tau$.

To put the system into operation, at the testing ground rooms were built for the vacuum pumps and system-control desk, utilities connecting the test silos containing liquid oxygen *3* and nitrogen *4* and a compressed-helium battery with a cooling system were fabricated and assembled, a test procedure was developed to produce the coolant and charge and cool the oxygen, and power-supply systems were developed and assembled for the vacuum pumps controlling the PGS units and the units performing parameter measurements.

Start-up and adjustment work was performed in cooperation with the SIAI: the coolant – a mixture of liquid oxygen and nitrogen – was produced in unit *5*, and charged into external vessel *1* of the assembly; the internal vessel was charged with liquid oxygen that was cleaned of impurities, and cooled.

The serviceability of the adsorption filter, which reliably cleans $N_2O$ and $CO_2$ impurities from the oxygen at flow rates not exceeding 3.5 tons/h, was confirmed experimentally as a result; the process of producing coolant was carried out and experience was acquired in its cooling and recharging; the composition of the evacuated vapors was measured and its variation with

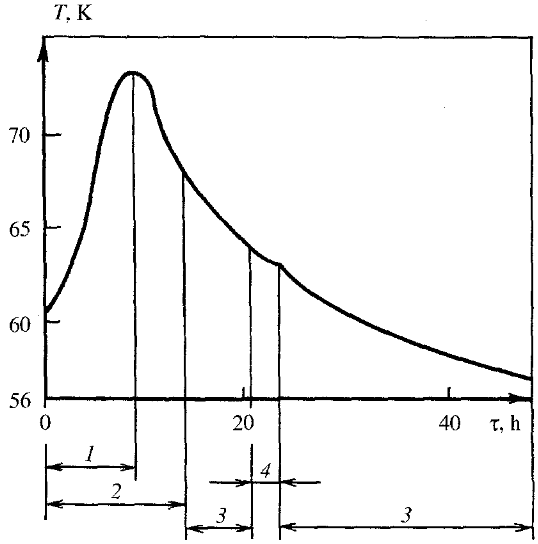


Fig. 3. Curves of oxygen temperature $T$ versus cooling time $\tau$ (in accordance with improved procedure).

TABLE 1

| Year | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | Σ |
|---|---|---|---|---|---|---|---|---|
| Amount of cooled $O_2$, tons | 240 | 550 | 694 | 1087 | 637 | 630 | 640 | 4378 |
| Number of cycles | 8 | 17 | 20 | 41 | 27 | 18 | 16 | 148 |

decreasing temperature determined; and the serviceability of the equipment and the correctness of the method of cooling oxygen was confirmed.

The standard process of the cooling of oxygen is shown in Fig. 2. Curve A represents the change in the temperature of the coolant averaged over two sensors as a function of evacuation time, while curve B represents the change in the average temperature of the oxygen being cooled in the interval vessel, which is submerged in the coolant. Upper curve C indicates the variation in the residual pressure in the coolant recess during evacuation. As follows from the plots, the coolant is cooled to 57 K under a residual pressure of 18 mm Hg; here, the temperature of the oxygen is 57.5 K and the duration of cooling is 87 h.

Production operations during the cooling of oxygen are as follows: 1) evacuation of coolant vapors by a VVN2-50 vacuum pump; 2) a pause in the evacuation in connection with the close of the work day; 3) evacuation of coolant vapors by NVZ-500 vacuum pumps; and 4) recharging of coolant (to make up for losses during evaporation).

The large volume of tests and the brief time allotted for the development of the units dictated the need to improve the production process to shorten its duration and to improve the safety of the work and the operating reliability of the equipment.

*The following measures were developed and implemented from the results of analysis*:

• the optimum (initial) composition of the coolant was determined; this simplified its recharge in the cooling process;

• double recharging with coolant of the initial composition is replaced by a single recharge (precooled nitrogen); this made it possible simultaneously to reduce the level of hydraulic hammers in the coolant cavity, which occur during recharging in the first cooling cycle. Implementation of this measure required changes in the pneumatic circuit; here, the nitrogen was cooled by the VVN2-50 pump in unit *5* simultaneously with the evacuation of coolant vapors in unit *1*;

• the charging of oxygen and its cooling, which had been previously accomplished in sequence, were combined; this not only reduced the overall time outlays, but also intensified the heat transfer by mixing of the oxygen; and

• continuous (round-the-clock) evacuation was implemented, since heating of the coolant and oxygen (with no night shift) was compensated by an evacuation of two-three hours.

During operation of the new oxygen-cooling system, 28 changes were made to the hydraulic circuit, and author's certificates were obtained for the most significant innovations.

As a result of implementation of these measures, the duration of the process of the charging and cooling of liquid oxygen was reduced from 87 to 50 h. Figure 3 shows the curves of oxygen cooling which was conducted in accordance with the improved procedure: *1*) charging of oxygen into vessel *1* of the unit; *2*) evacuation of coolant vapors by the VVN2-50 pumps; *3*) evacuation of coolant vapors by the NVZ-500 pumps; and *4*) maintenance of the coolant level with cooled nitrogen.

More than 140 oxygen-cooling cycles (see Table 1) were carried out during the operating period (1985–1992) of the system developed for oxygen cooling; no delays due to a lack of cooled oxygen occurred.

Thus, the cooling of oxygen to 57–58 K has been mastered for the first time commercially using a mixture of liquid oxygen and nitrogen as a new coolant. Retaining the liquid state to 50 K, the new coolant can be effectively employed in place of liquid nitrogen as an auxiliary coolant in cryogenic power lines, and in microcryogenic systems, as well as in the commercial production of liquid hydrogen and helium.